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(54) **Ophthalmic Lens having a Progressively Variable Focal Power**

(57) An ophthalmic lens having a progressively variable focal power, the lens having a far vision viewing zone (F) in the upper portion of the lens, a near vision viewing zone (N) in the lower portion of the lens, an intermediate vision viewing zone (P) extending from the said upper portion to the said lower portion in the intermediate portion of the lens and a principal meridian (MM') extending substantially in the central and vertical direction, the said far vision viewing zone (F) optionally being horizontally divided into three areas (F1, F2, F3) where the astigmatism is at its least in the centre area (F1) thereof and is greater in the areas (F2, F3) on opposite sides of said centre area (F1), said centre area (F1) having a portion of said principal meridian MM' extending substantially through its central portion.

Fig.1.

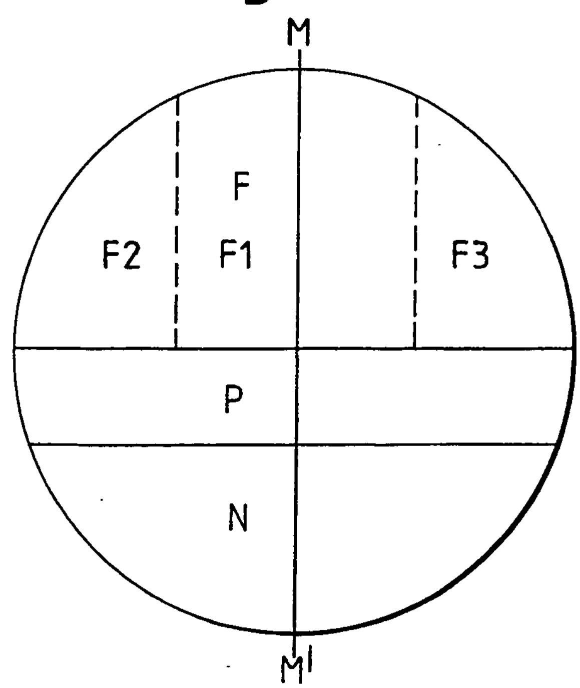

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Fig.1.

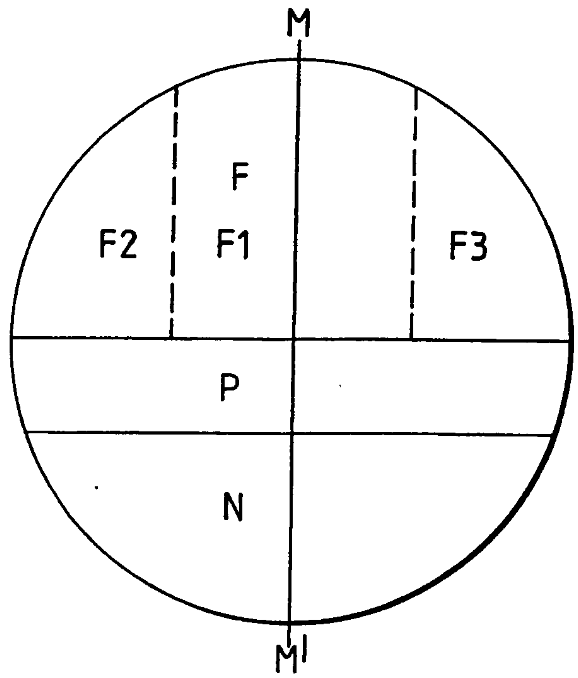


Fig.2.

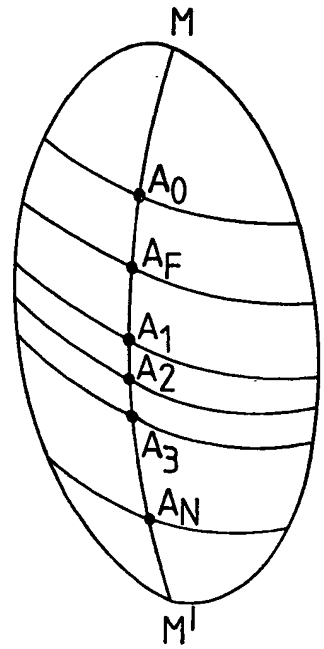


Fig.3.(a).

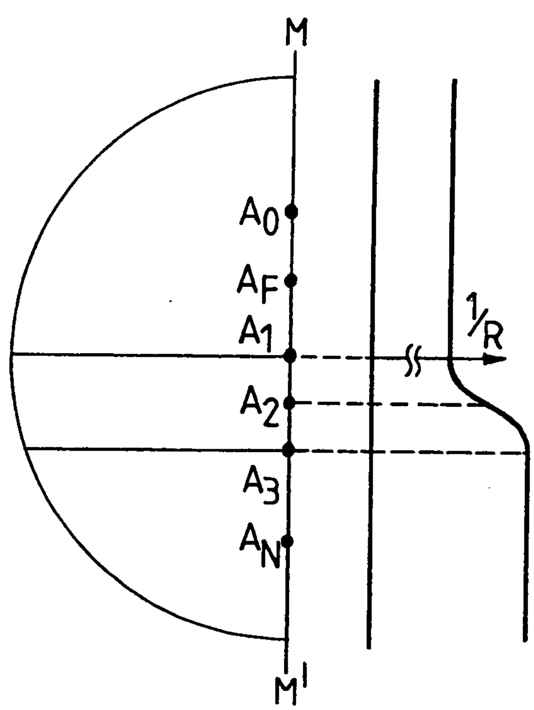


Fig.3.(b).

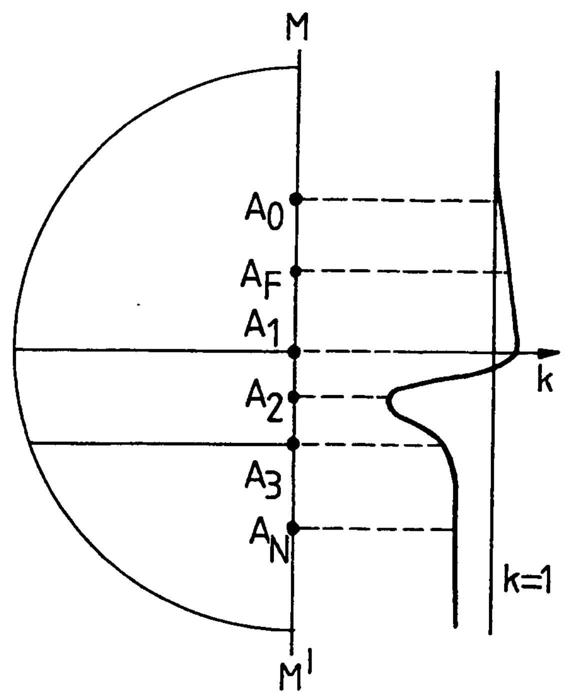


Fig.4.

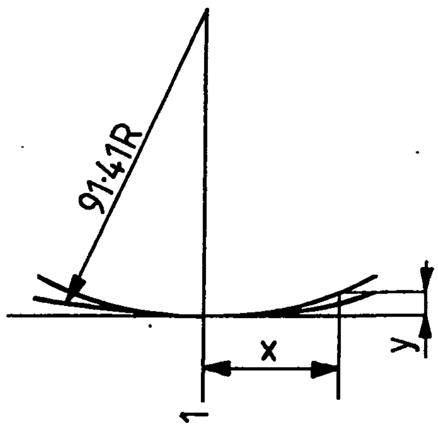


Fig.5.

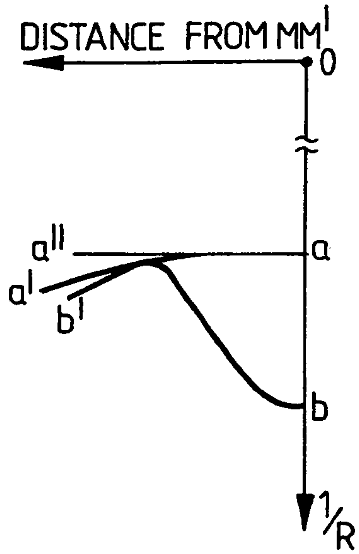


Fig.7.

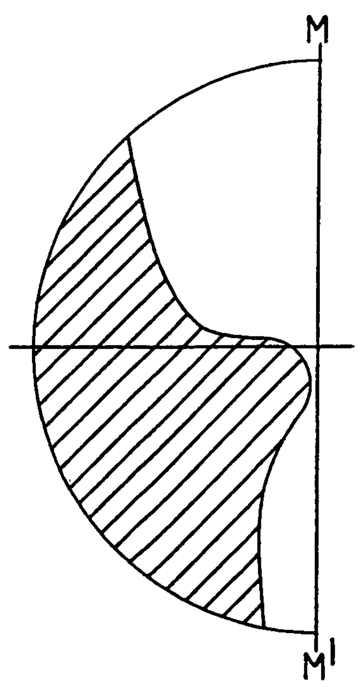
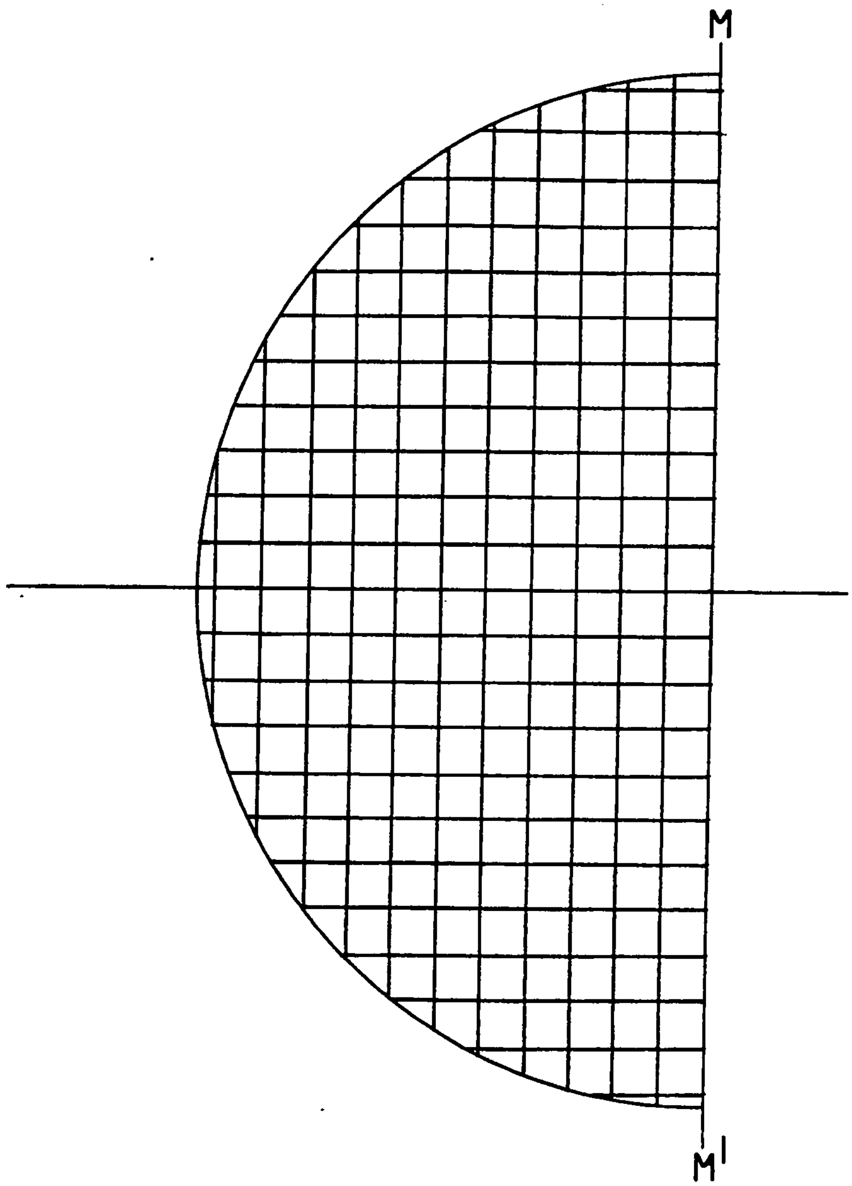


Fig.6.



SPECIFICATION

Ophthalmic Lens Having a Progressively Variable Focal Power

This invention relates to a lens having a progressively variable focal power.

The object of this invention is to provide a person whose ability to control his crystalline lens has weakened, with lenses which enable comfortable far and near vision to be achieved.

Japanese Patent Publication No. 49—3595 (which corresponds to U.S. Patent Specification No. 3,687,528) and Japanese Laid Open Patent Publication No. 50—46348 (which corresponds to British Patent Specifications Nos. 1,484,382, 1,484,383 and 1,484,196) concern conventional progressively variable power lenses. The lenses disclosed in these Specifications have a far vision viewing zone (hereinafter referred to as a far zone), an intermediate vision viewing zone (hereinafter referred to as an intermediate zone) and a near vision viewing zone (hereinafter referred to as a near zone). Furthermore, the inventions described in these specifications are based upon the well-known technique that the lens is provided with an umbilical principal meridian having a curvature whose value is gradually changed by adding a predetermined addition of focal power.

The lens according to Japanese Patent Publication No. 49—3595 relies upon the idea that the aberration which is inevitably caused in a progressive power lens should be distributed uniformly over the whole surface of the lens so as to make the distortion of the image small and so as to reduce the apparent movement of the image when the wearer moves his face. The line of intersection between the plane orthogonal to the principal meridian and the refractive surface is circular only at its centre point. In the upper portion therefrom, the radius of curvature on the line of intersection is reduced as it becomes more distant from the principal meridian. In the lower portion, it is increased as it becomes more distant from the principal meridian. Both lines of intersection in the upper and lower portions are non-circular curves. Thus, all but one portion have non-circular curves. Accordingly, it goes without saying that the clear viewing zone (in the range where the astigmatism is 0.5 diopters or less) is narrow in the near zone. Furthermore, it is also very narrow in the far zone. Since the wearer looks out over a broad range when looking at a distant place, such a narrow zone is very inconvenient.

The idea underlying the invention disclosed in Japanese Laid Open Patent Publication No. 50—46348 is that the clear viewing zone in the far zone and in the near zone should be given a large area and that the aberration should be concentrated at the periphery of the clear viewing zone in a long and narrow strip so as to obtain relatively good view in the portion outside the aberration portion. For instance, the intermediate zone is laterally divided into five portions and the centre portion of them is made to be a region where aberration is small and the clear viewing zone is large. In the two outside portions, the skew distortion is arranged to be zero. Each portion between the centre portion and the respective two outside portions is a boundary portion. Consequently, aberration is concentrated in these boundary portions and astigmatism becomes very large and the image is much distorted there. When seeing a horizontal line, its central portion is inverted U-shaped (∩) but the line is horizontal at its most outside portions, and so, the line is suddenly curved at the boundary portions.

As well as the near zone, its intermediate zone has a circular surface, and moreover, the whole surface of the far zone is a spherical surface. Therefore, the clear viewing zones of the far (vision viewing) zone and of the near (vision viewing) zone are extremely large as compared with the lens according to Japanese Patent Publication No. 49—3595. Because of the large clear viewing zones and amendment of the skew distortion of the most outside regions, the aberration is concentrated most in the boundary regions. When these lenses are worn, the apparent movement of the image is strongly felt, which is uncomfortable. So, despite the good feature that the lens has broad clear viewing zones for far and near visions, this lens is not easy to use.

The above-mentioned lenses are suitable for some special uses, e.g. for certain kinds of sports, reading, making notes, and the like. However, these lenses have the faults mentioned above.

According therefore to the present invention, there is provided an opthalmic lens having a progressively variable focal power, the lens having a far vision viewing zone in the upper portion of the lens, a near vision viewing zone in the lower portion of the lens, an intermediate vision viewing zone extending from the said upper portion to the said lower portion in the intermediate portion of the lens, and a principal meridian extending substantially in the central and vertical direction, the said far vision viewing zone being horizontally divided into three areas where the astigmatism is at its least in the centre area thereof and is greater in the areas on opposite sides of said centre area, said centre area having a portion of said principal meridian extending substantially through its central portion.

Preferably the width of the centre area of the far vision viewing zone is more than 30 mm.

The invention also comprises an ophthalmic lens having a progressively variable focal power, the lens having a far vision viewing zone in the upper portion of the lens, a near vision viewing zone in the lower portion of the lens, an intermediate vision viewing zone where the refractive power on the surface progressively changes towards the lower portion from the upper portion, and a principal meridian extending substantially in the central vertical direction; the arrangement being such that in the lower portion of the far vision viewing zone, the line of intersection between the

refractive surface and the plane orthogonal to the principal meridian is a non-circular curve whose radius of curvature decreases as the line of intersection becomes more distant from the principal meridian, the decreasing rate of the value of said radius of curvature successively decreasing down to 0 (whereby the curve becomes spherical), and thereafter becomes constant; the arrangement also being such that in the near vision viewing zone, the radius of curvature of the line of intersection between the refractive surface and the plane orthogonal to said principal meridian increases as the line of intersection becomes more distant from the principal meridian and thereafter decreases, the increasing rate of said radius of curvature being nearly constant except adjacent to said intermediate vision view zone; and the arrangement also being such that in the intermediate vision viewing zone, the line of intersection between the plane orthogonal to said principal meridian and the refractive surface is a non-circular curve whose radius of curvature increases as the line of intersection becomes more distant from the principal meridian except for adjacent to said far vision viewing zone, the increasing rate of said radius of curvature being at its maximum in the nearly central portion of said intermediate vision viewing zone; the whole of said principal meridian being umbilical and, in said intermediate vision viewing zone, having a change of curvature so as to give a predetermined addition of focal power from said far vision viewing zone toward said near vision viewing zone.

Preferably the skew distortion $\partial^2 f/\partial x \partial y$ at the side portions of the intermediate vision viewing zone is 0.0003 to 0.0020 in the range where the addition of focal power is 1 to 3 diopters, x and y being distances in the horizontal and vertical directions respectively from the geometrical centre.

The present invention thus provides a clear viewing zone having an area which is convenient for daily use in each of the far, intermediate and near (vision viewing) zones, and the amount of aberration in the peripheral portions is small.

The far zone may be horizontally divided into three portions the centre area of which is a clear viewing zone whose astigmatism is within 0.5 diopters. In the portions on both sides of the centre area, astigmatism may be made more than 0.5 D. As a result, astigmatism and distortion are reduced at the outsides of both the intermediate zone and of the near zone.

As stated above, the width of the centre area may be more than 30 mm. This value of 30 mm almost corresponds to the region of the rotating angle of 30° of eyes, which region is most frequently used.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:—

Figure 1 is a front view of a lens having a progressively variable focal power according to this invention,

Figure 2 is a perspective view of a lens having a progressively variable focal power according to this invention,

Figure 3(a) is a view showing the change of curvature along the principal meridian of the lens according to this invention,

Figure 3(b) is a view showing the change of the value of k (aspherical coefficient) when the line of intersection between the refractive surface and the plane orthogonal to the principal meridian of the lens having a progressively variable focal power according to this invention is arranged as a quadratic curve,

Figure 4 shows the shape of the line of intersection in the far vision viewing zone of a lens having a progressively variable focal power according to this invention,

Figure 5 shows the change of the curvature along the line of intersection passing through the points A_0, A_F and A_N.

Figure 6 is a view of the distortion of a square grid as seen through a lens having a progressively variable focal power according to this invention, and

Figure 7 is a view showing the clear viewing zone of a lens having a progressively variable focal power according to this invention.

As shown in Figure 1, the lens according to this invention has the principal meridian MM′ in an almost central vertical direction. Along the principal meridian MM′, there are arranged successively from the upper portion a far zone F, an intermediate zone P and a near zone N, these zones having contiguous boundaries.

The far zone F is divided into three areas, which are arranged horizontally side by side, namely, an area F_1 having the principal meridian MM′ almost at its centre, and areas F_2 and F_3 which are on opposite sides respectively of the area F_1.

The curvature of the principal meridian MM′ is progressively changed in the intermediate zone P so as to give a predetermined addition of focal power. The form of the change can be represented as a straight line, a cubic line or other arbitrary forms.

In order to make the astigmatism along the principal meridian MM′ as small as possible, the whole line of the principal meridian from the zone F to the zone N should be made of umbilical points. The umbilical point is a point at which the radii of curvature in the directions of the main radii of curvature are the same. It appears to be a spherical surface.

In the lower portion of the horizontally central area F1 of the far (vision viewing) zone F, the line of the intersection between the plane orthogonal to the principal meridian MM′ and the refractive surface of the lens is represented as a non-circular curve whose radius of curvature decreases as the line of intersection becomes more distant from the point of intersection with the principal meridian MM′. However, the degree of non-

circularity is relatively small since almost the whole portion of the area F_1 is clear viewing zone.

As the radius of curvature on the principal meridian MM′ in the far zone F is larger than that in the near zone N, if the lines of intersection in both the far zone F and the near zone N are circular, the difference of power becomes gradually larger with increasing distance from the point of intersection. For this reason, the above-mentioned non-circular curve is adopted in order to make such a difference small and in order to smooth the connection from the far zone F to the near zone N through the intermediate zone P. As a result, astigmatism and distortion in the connecting portions can be made small.

The line of intersection in the central area F_1 of the far zone F loses its non-circularity as it goes to the upper portion of the principal meridian MM′. That is to say, it becomes gradually almost circular and becomes just circular at a particular portion. Once it becomes circular, such a state is fixed. Thus, in the upper portion of the far zone F, the form of the above-mentioned line of intersection becomes circular and so the astigmatism becomes very small and the clear viewing zone for far vision can be obtained over a wide field. This is very convenient because the wearer usually looks through the upper portion of the lens when looking into the distance and at that time a wide clear viewing zone is necessary in the upper portion of the far zone F.

The two areas F_2 and F_3 on the opposite sides of the far zone F are rarely used when lenses of this invention are worn as glasses. Accordingly, the areas F_2, F_3 do not adversely affect the eyes even if they produce somewhat large aberration. So, the lines of intersection of these areas F_2 and F_3 are a little different from the curve of the area F_1. By utilizing this structure, aberrations in the near zone N and the intermediate zone P (especially in respective side portions of these zones) are reduced and a concentration of aberration in a particular portion of the lens surface is avoided.

In the near zone N, the line of intersection between the plane orthogonal to the principal meridian MM′ and the refractive surface of the lens is a non-circular curve where the value of the radius of curvature increases at first and thereafter decreases as the line of intersection becomes more distant from the point of intersection with the principal meridian MM′. The value of the radius of curvature is made to increase at first for the purpose of connecting the far zone and the near zone smoothly. In this case, it is necessary that the above-mentioned increasing rate should be made to be a little large in order to provide a clear viewing zone which is wide enough to be easily used. If the said increasing rate continuously increases, the aberration becomes too large as it approaches the side portions. So, the increasing rate should be made to decrease from a certain portion. Then, the distortion at the sides of the near zone N can image is not very evident, and moreover the astigmatism can be also made small.

In the intermediate zone P, as the line of intersection between the plane orthogonal to the principal meridian MM′ and the refractive surface of the lens becomes more distant from the point of intersection with the principal meridian MM′, the radius of curvature decreases at the side where it is connected to the far zone F, and at the side where it is connected to the near (vision viewing) zone N, the radius of curvature increases. (Thereafter, in the same manner as in the near zone N, the radius of curvature decreases). The radius of curvature changes from a decrease to an increase successively between the sides where it is connected to the near zone and the far zone. This change is not monotonous. The line of intersection where the increasing rate is at its maximum exists in the almost central portion of the intermediate zone P. Then, the far zone F and the near zone N can be connected more smoothly and the astigmatism near the principal meridian MM′ decreases and, as a result, the field for the intermediate vision is broadened.

Lenses made of CR-39 having a zero-diopter distance power and a 2.0 diopter power addition will be described as one of the embodiments according to this invention.

In Figures 2 and 3, the values of the refractive power at each point are as follows:

Point A_1	P_{w1}=0 diopter
Point A_2	P_{w2}=1.0 diopter
Point A_3	P_{w3}=2.0 diopters

Points A_1 and A_3 are optical centres of the far zone F and of the near zone N, respectively.

The point A_1 is at the junction of the zones F and P on the principal meridian MM′, the point A_2 is the centre point between the points A_1 and A_3, and the point A_3 is at the junction of the zones P and N on the principle meridian.

The point A_0 in Figure 2 is nearly the centre point of the far zone F on the principal meridian MM′, the point A_F is nearly the centre point between the points A_0 and A_1, and the point A_N is nearly the centre point of the near zone N on the principal meridian MM′.

The value of the curvature of the principal meridian MM′ is constant in the far zone F and in the near zone N. It changes in accordance with the sine curve from the point A_1 to the point A_3. The values at the respective points are as follows:—

Point A_1	1/R1=0.01094 (R1=91.41 mm)
Point A_2	1/R2=0.01279 (R2=78.17 mm)
Point A_3	1/R3=0.01479 (R3=67.60 mm)

Thus, there is no change in power on the principal meridian MM′ in the far zone F and in the near zone N, and so, a good field of vision can be obtained

In the far zone F, the line of the intersection between the plane orthogonal to the principal meridian MM′ and the refractive surface of the lens is represented as, for instance, the quadratic curve

$$y=cx^2/(1+\sqrt{1-kc^2x^2}),$$

where k is the aspherical coefficient, and c is the curvature (1/R). The form of the line of intersection is shown in Figure 4. The radius of curvature becomes smaller as the line of intersection becomes more distant from the principal meridian. In Figure 4, the dotted line shows a circular curve. The form of the line of intersection becomes more different from the circle because the value of k becomes greater as the line of intersection goes to the lower portion of the far zone F. As the line of intersection goes to the upper portion of the far zone F, the value of k becomes smaller (i.e. the difference in shape from a circle is made smaller). In the intermediate portion or near portion of the far zone F, k becomes 1 (circle) and k is always 1 in the portion above the intermediate portion. The change of k is shown in Figure 3(b). The curvature on the line of intersection passing the point A_F is that of a curve a—a′ shown in Figure 5, and that on all the line of intersection above the line of intersection passing the point A_0 is that of a line a—a″. (In both cases, only a half of the line of intersection is shown). The width of the central area F_1 is about 40 mm.

The line of intersection in both the near zone N and the intermediate zone P is not so simple as that in the far zone F. It is a special curve including a term of higher degree. But it is similar to the quadratic curve when it is near the principal meridian MM′ (10 mm or so on one side). The change of k at this time is shown in Figure 3(b) after the value of k in the far zone F.

As shown in Figures 3(a) and 3(b), the curvature of the value of k of the line of intersection in the near zone N are not so changed and are almost constant except in the portion which adjoins the intermediate zone P. The width of the clear viewing zone for the near vision is also almost constant. The change of the curvature on the above-mentioned line of intersection passing the point A_N is represented as the curve b—b′ shown in Figure 5.

The far zone F and the near zone N are connected through the intermediate zone P whose value of k is made to be at its minimum in the almost central portion of the zone P (rather near to the near zone N), as shown in Figure 3(b). As compared with the case in which k of the intermediate zone P is made to change monotonously, both distortion and astigmatism are improved in this case.

Figure 6 shows the distortion when viewing a square grid through the lens according to this invention.

As the upper half portion of the far zone F is substantially a spherical surface there is no distortion. So, the square grid viewed through the lens is left as it is and its size is the same. In the lower portion, as mentioned before, the form of the line of intersection is an aspherical curve and the radius of curvature decreases as the line of intersection becomes more distant from the principal meridian MM′, which can be seen from Figure 6 where the intervals between the vertical lines of the grid is broadened by degrees.

In the near zone N, there is a portion where the grid is seen to be a little bigger than its true size and to be almost square. This portion is almost identical with the clear viewing zone of the near zone N. In the same manner as in the far zone F, the change of the radius of curvature of the line of intersection is shown as the change of the interval between the vertical lines of the grid.

In the external portion from almost the centre between the principal meridian MM′ and the edge portion of the lens, the vertical lines of the grid are seen to be nearly straight lines but they are not just vertical and they are inclined a little. This is because the value of k (non-circular coefficient) changes in the far zone. Also in the intermediate zone P and the near zone N, the inclination of the vertical lines is left as the skew distortion is not amended. The vertical lines of grid are not just vertical but are inclined a little. And the apparent movement of the image felt when the face or eyes move is less when such lines are seen to be straight than when they are seen to be suddenly refracted. Furthermore, the concentration of astigmatism is small, so that little blur is felt, and the glasses become easy to use.

As regards the apparent movement of the image, it is the same with respect to the horizontal lines. In the outer portion of the near zone N and in the intermediate zone P, the horizontal lines of the grid are nearly horizontal but are seen to go down as they approach the outer side. In this case, the amount of refraction is made smaller and the change becomes smooth, and as a result, the apparent movement of the image is rarely felt.

On the whole, the grid which is seen through this lens has no portion where there is sudden change, and the apparent movement of the image felt by the eyes is small.

The value of the skew distortion of the lens according to this invention is as follows. It is expressed as $\partial^2 f/\partial x\partial y$. Here, $z=f(x,y)$, where x and y are distances in the horizontal and vertical directions with the geometrical centre (optical centre in the far zone in this embodiment) at the origin, and z is the distance of the refractive surface from the plane x—y. When the skew distortion is 0, $\partial^2 f/\partial x\partial y=0$. However, in a lens of the present invention having a 2-diopter power addition, the value of $\partial^2 f/\partial x\partial y$ is 0.0007 to 0.0016 in the side area of the intermediate zone P. This value becomes larger when the power addition is larger. Accordingly, in the lens having a progressively variable focal power according to this invention with 1 to 3-diopter power addition, the value of $\partial^2 f/\partial x\partial y$ is in the range of 0.0003 to 0.0030

The lens according to this invention has such a value of the skew distortion because a special non-circular curve is adopted in the intermediate zone P. Such a value is not amended in order to obtain the above-mentioned effects having regard to the whole balance of the aberration of the lens.

The clear viewing zone for the far vision, near vision and the intermediate vision is in the range as shown in Figure 7. It is broad enough for daily use. Especially in the far vision viewing zone, a sufficient clear viewing zone is provided when one takes the rotating angle of the eyes into consideration. In Figure 7, the hatched portion shows the portion where the astigmatism is large. The outer area has the greatest value of the astigmatism. However, the value does not increase rapidly but slowly.

Thus in the lens according to this invention, the clear viewing zone for the far vision through which it is necessary to see a wide range is very large and the clear viewing zone of the near zone and the intermediate zone also has a width which does not make the user feel any inconvenience in everyday life. As the astigmatism is dispersed so as not to concentrate in a particular portion and the clear viewing zone is arranged as mentioned above, a lens having a progressively variable focal power which is the most suitable for daily general use can be obtained.

At the time of the actual use of the lens having a progressively variable focal power according to this invention, the point A_1 is made to be the centre point of the lens and the lens is rotated in a manner such that the point A_3 is a little inside. This is because the distance between the pupils of a person's eyes become smaller when he looks at a material object at no great distance.

Claims

1. An ophthalmic lens having a progressively variable focal power, the lens having a far vision viewing zone in the upper portion of the lens, a near vision viewing zone in the lower portion of the lens, an intermediate vision viewing zone extending from the said upper portion to the said lower portion in the intermediate portion of the lens, and a principal meridian extending substantially in the central and vertical direction, the said far vision viewing zone being horizontally divided into three areas where the astigmatism is at its least in the centre area thereof and is greater in the areas on opposite sides of said centre area, said centre area having a portion of said principal meridian extending substantially through its central portion.

2. Ophthalmic lens as claimed in claim 1, wherein the width of the centre area of the far vision viewing zone is more than 30 mm.

3. An ophthalmic lens having a progressively variable focal power, the lens having a far vision viewing zone in the upper portion of the lens, a near vision viewing zone in the lower portion of the lens, an intermediate vision viewing zone where the refractive power on the surface progressively changes towards the lower portion from the upper portion, and a principal meridian extending substantially in the central vertical direction; the arrangement being such that in the lower portion of the far vision viewing zone, the line of intersection between the refractive surface and the plane orthogonal to the principal meridian is a non-circular curve whose radius of curvature decreases as the line of intersection becomes more distant from the principal meridian, the decreasing rate of the value of said radius of curvature successively decreasing down to 0 (whereby the curve becomes spherical), and thereafter becomes constant; the arrangement also being such that in the near vision viewing zone, the radius of curvature of the line of intersection between the refractive surface and the plane orthogonal to said principal meridian increases as the line of intersection becomes more distant from the principal meridian and thereafter decreases, the increasing rate of said radius of curvature being nearly constant except adjacent to said intermediate vision viewing zone; and the arrangement also being such that in the intermediate vision viewing zone the line of intersection between the plane orthogonal to said principal meridian and the refractive surface is a non-circular curve whose radius of curvature increases as the line of intersection becomes more distant from the principal meridian except for adjacent to said far vision viewing zone, the increasing rate of said radius of curvature being at its maximum in the nearly central portion of said intermediate vision viewing zone; the whole of said principal meridian being umbilical and, in said intermediate vision viewing zone having a change of curvature so as to give a predetermined addition of focal power from said far vision viewing zone toward said near vision viewing zone.

4. Ophthalmic lens as claimed in any preceding claim wherein the skew distortion $\partial^2 f/\partial x \partial y$ at the side portions of the intermediate vision viewing zone is 0.0003 to 0.0020 in the range where the addition of focal power is 1 to 3 diopters, x and y being distances in the horizontal and vertical directions respectively from the geometrical centre.

5. An ophthalmic lens having a progressively variable focal power substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

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